National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

Development of In Situ Instruments for Planetary Exploration – Unique Challenges in Design, Development, and Execution

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- Susanne Douglas

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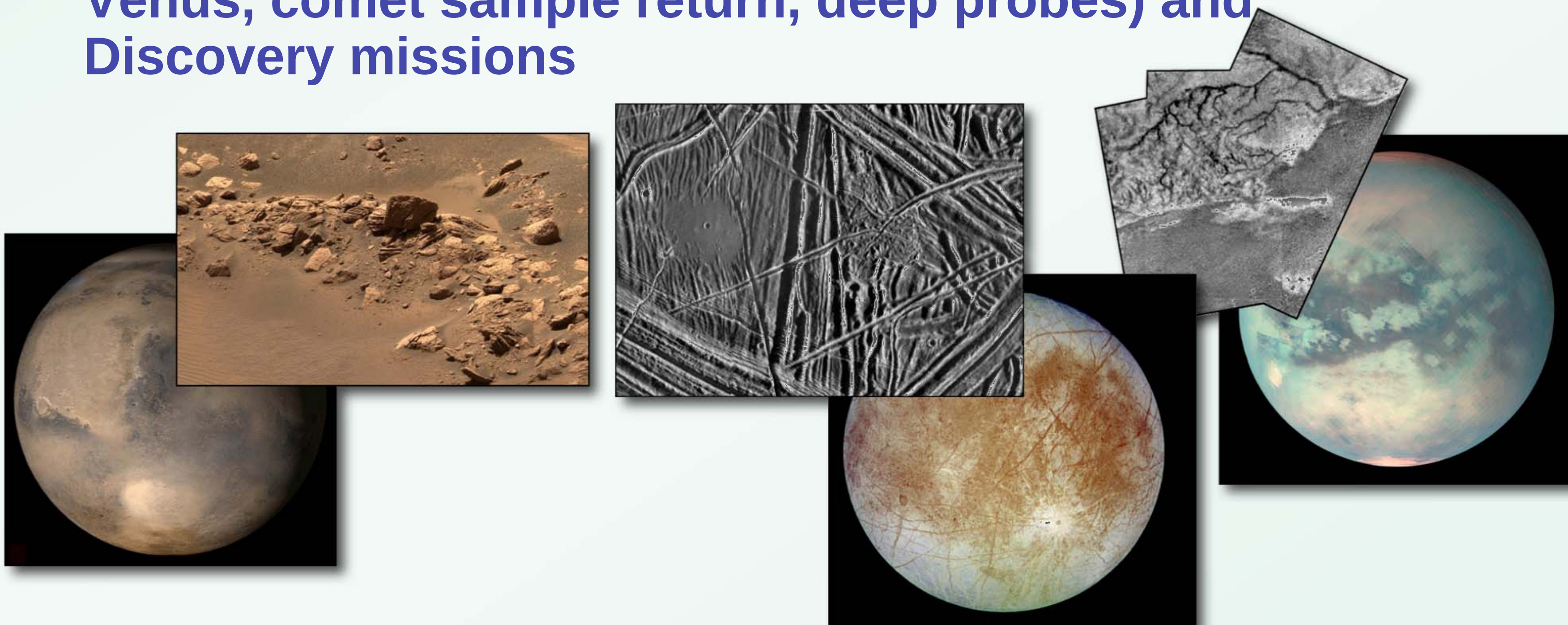
JPL

In Situ Instrumentation

- **Enabling the planetary science community to be ready for Flagship Astrobiology missions of the next decade**
  - Mars Astrobiology Field Laboratory
  - Europa Pathfinder Lander
  - Titan Organic Explorer
- **Prepare the capabilities for New Frontiers missions (e.g. Venus, comet sample return, deep probes) and Discovery missions**

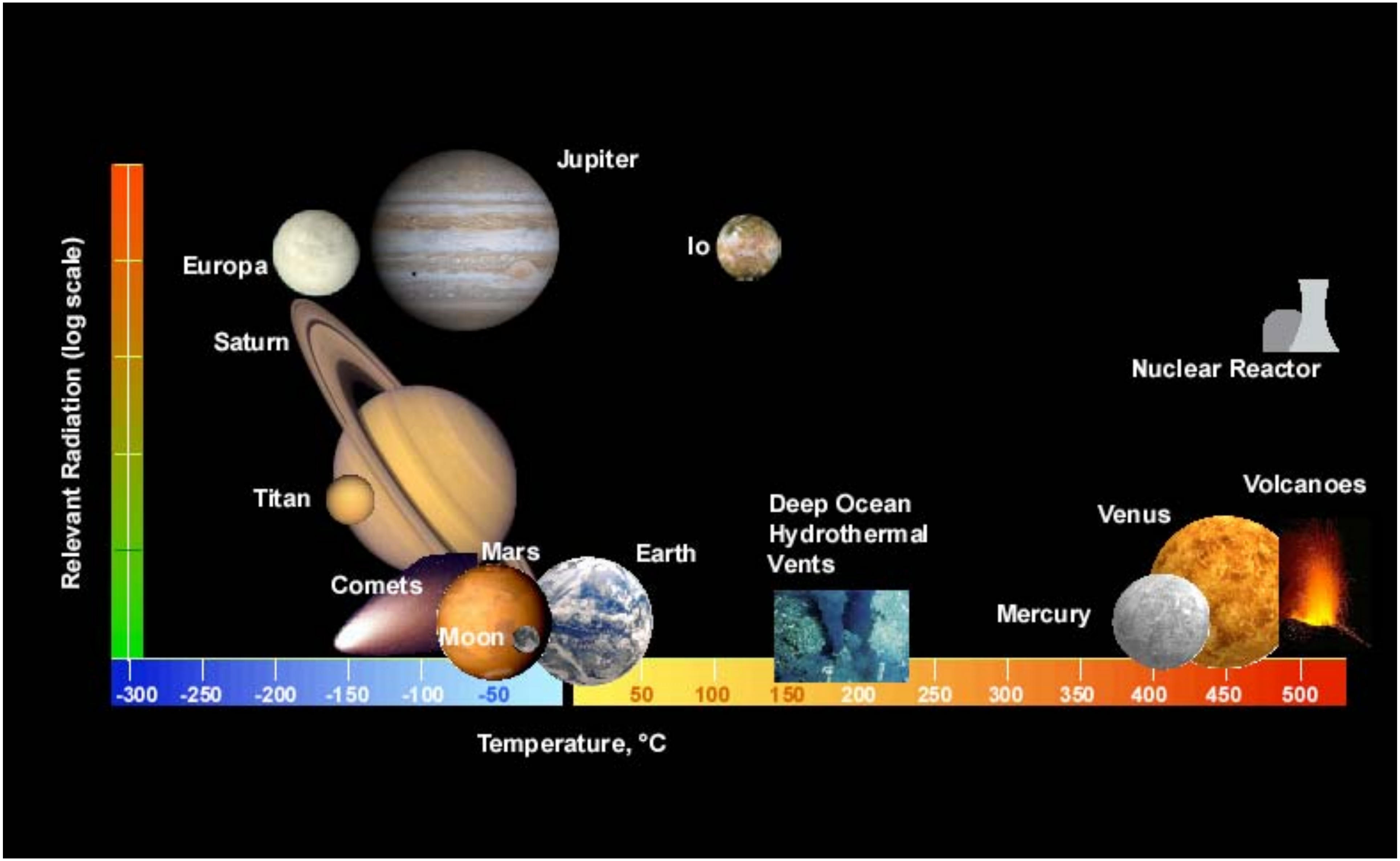


Space In Situ Instrumentation still in its Infancy

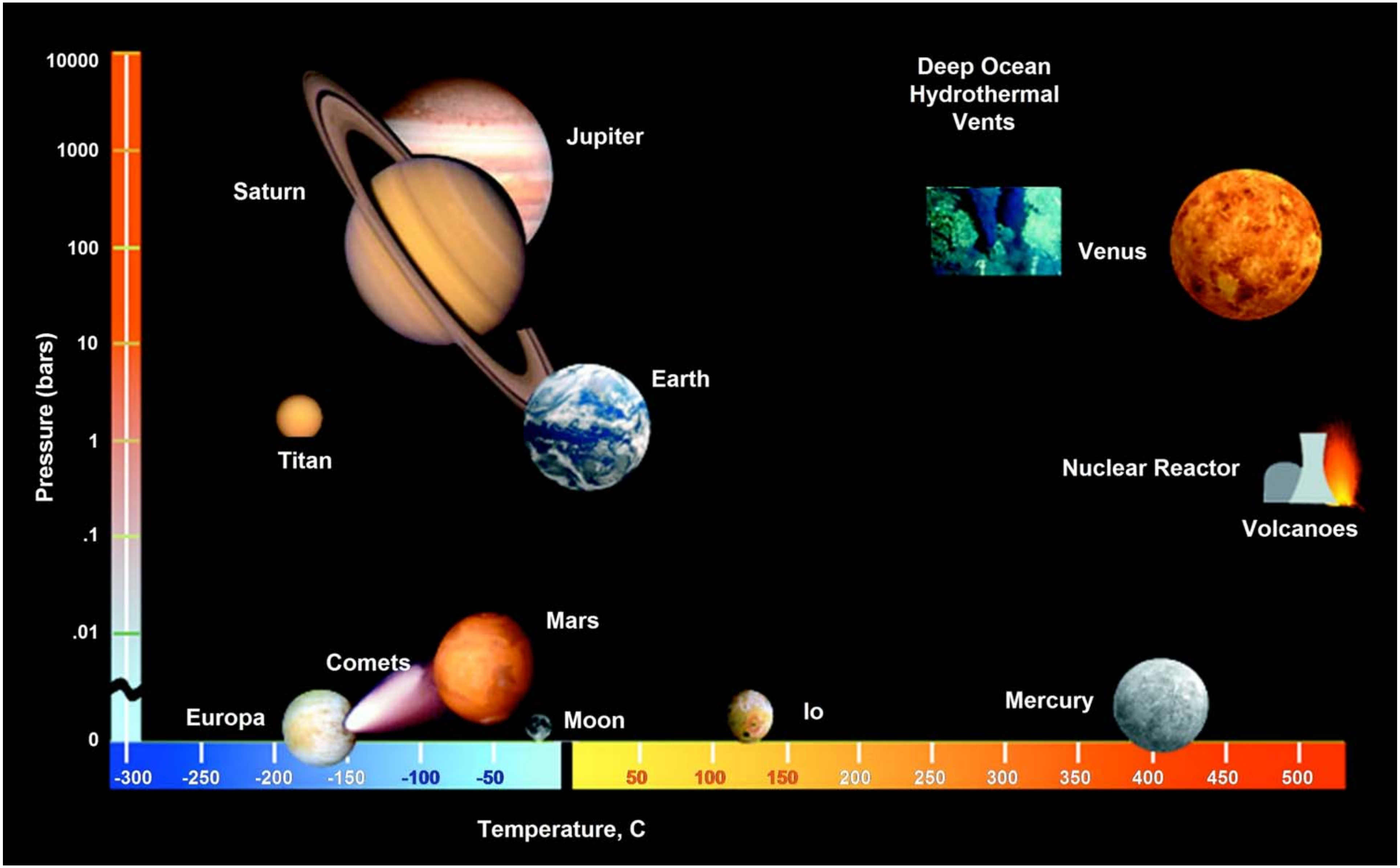
- Remote sensing has been operational for decades
- Viking was first planetary mission to use in situ instruments in 1976. Hiatus of 21 years before Pathfinder in 1997
- Dearth of instrumentation was remedied somewhat by PIDDP, MIDP, ASTID and ASTEP
- In situ analysis complicated because answering specific science questions requires specific technologies suited to specific extreme environment
- Instrumentation may be based on photon sources, electron sources, mass spectrometry, wet chemical techniques, etc.
- Process to develop in situ instrumentation is long, complicated and requires high degree of system architecting and engineering
- Testing must be done in the field and on the mission platform as well as in the expected environment
- Must look at end-to-end instrumentation, including sample acquisition and handling, sample preparation, IT, control etc.

In Situ Sample Analysis is where remote sensing instrumentation was in the 1970's

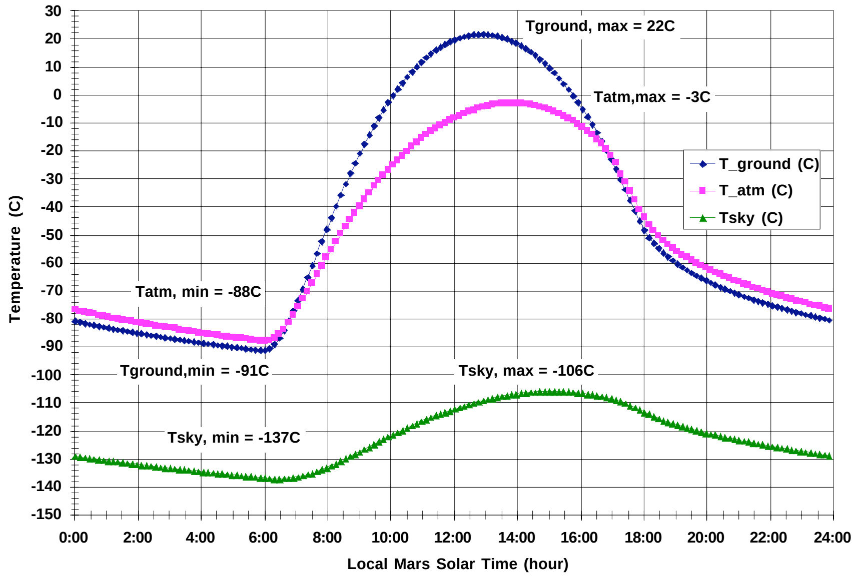
Planetary Extremes

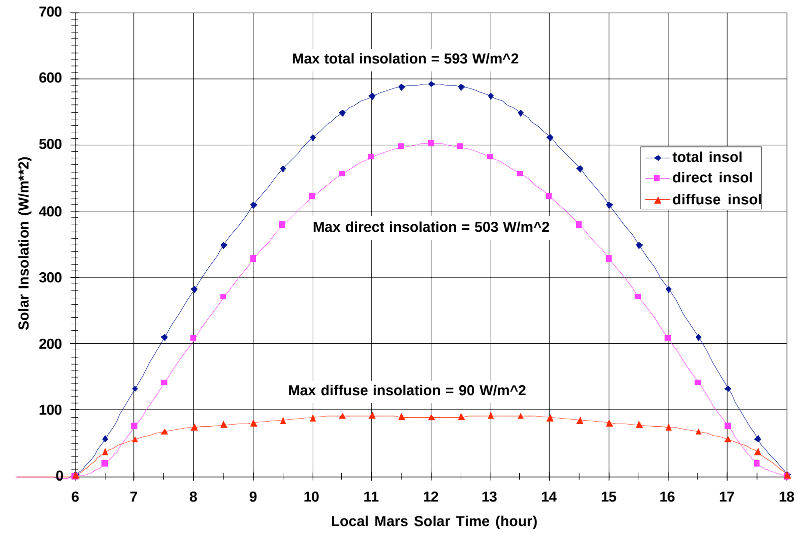


Planetary Extremes



Mars Surface Environment

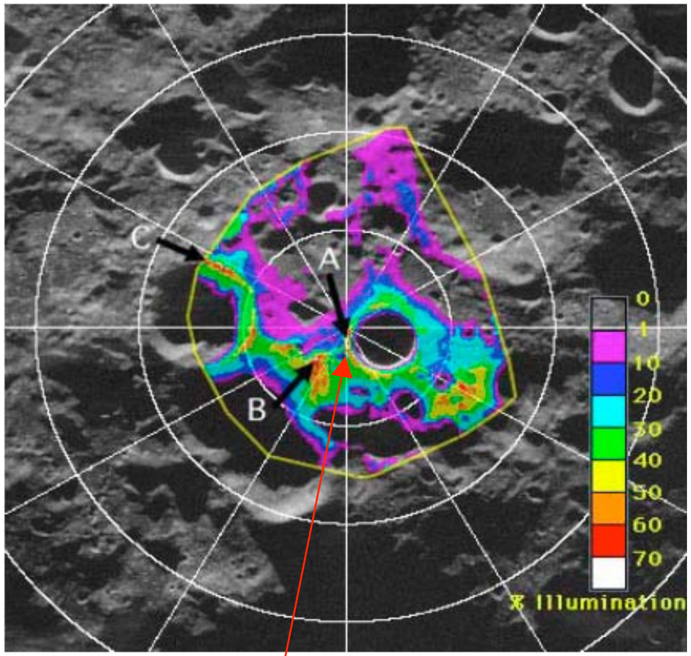




- Driven by landing site latitude (10ºN to 15ºS), time of year (L_S = 328 at BOM, L_S = 30 at EOM), ground albedo (0.12 to 0.25) and inertia (rock distribution), dust level (Tau = 0.2) in atmosphere & elevation (-1.3km, MOLA)
- Global Circulation Model predicts ground, atmosphere & sky temps, solar insolation during day
- Wind speeds from Viking data (0 to 20 m/sec)

Lunar Precursor Mission Environment

- **Analyze a large scale Lunar survey/assay mission in the permanently dark S. Polar Cap craters:**
- **Key environmental drivers include:**
  - 40K temperature in shadowed areas is challenge for any type of actuation/thermal control;
  - While surface rock population is not significant, crater impact frequency is extremely large and represents major hazard to landing/mobility systems;
  - 1/6g gravity has impact on surface system stability;
  - Radiant heating in lit areas can cause huge temperature deltas in structures/components;
  - Lunar dust mostly silica which exhibits properties similar to **splintered glass;**
  - Lunar vacuum coupled with temp extremes rqrs unique approach to selection of actuators (brushless) and lubricant;



Likely target- Shackleton Crater @ 90deg S. Polar Cap

- **Smooth, mantled surface with fractures: are the properties of Europa's regolith similar to those of compacted snow?**

Europa Surface Analogue

Europa's surface:

- **Is it fluffy?**
- **Is it crunchy?**
- **Is it bare solid ice?**

Answer:

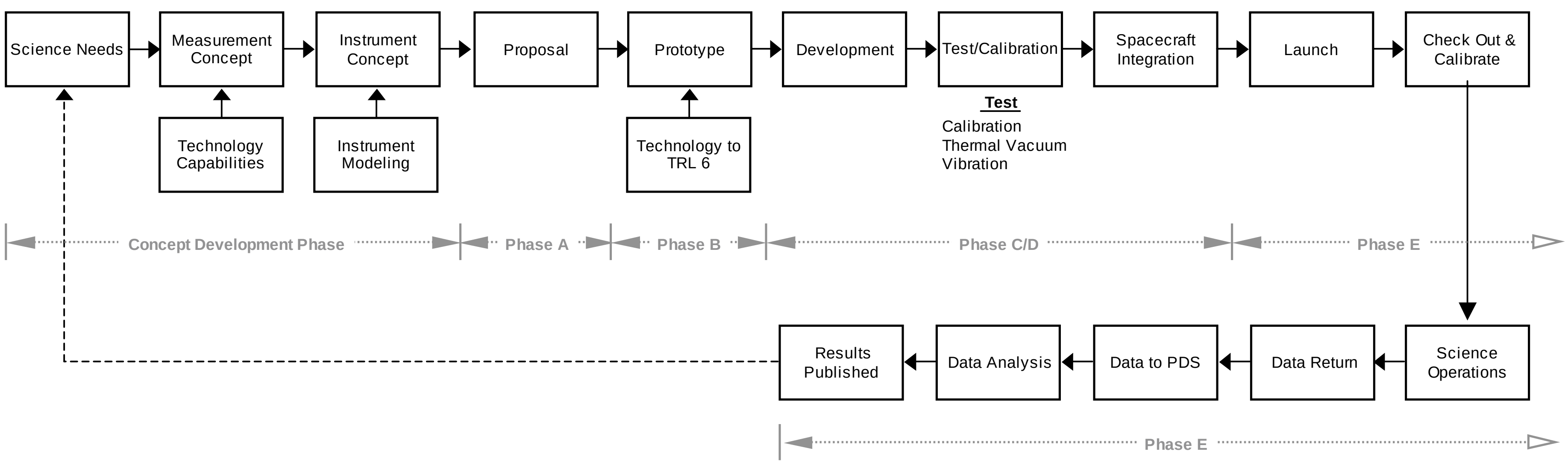
a. All of the above
b. We don't really know.

Our lander must be able to survive no matter what the correct answer turns out to be.

Other Parameters

Temperatures:	Daytime ~ 130 K
	nighttime ~ 80 K
Ambient Radiation:	~ 20 Rad /sec
Atmosphere:	Negligible
Rotation Period:	3.55 Earth days
Radius:	1565 km
Surface Gravity:	~1.3 m / sec 2 (82% of Lunar g)

Life Cycles of Remote Sensing compared to In Situ Instrumentation: Remote Sensing



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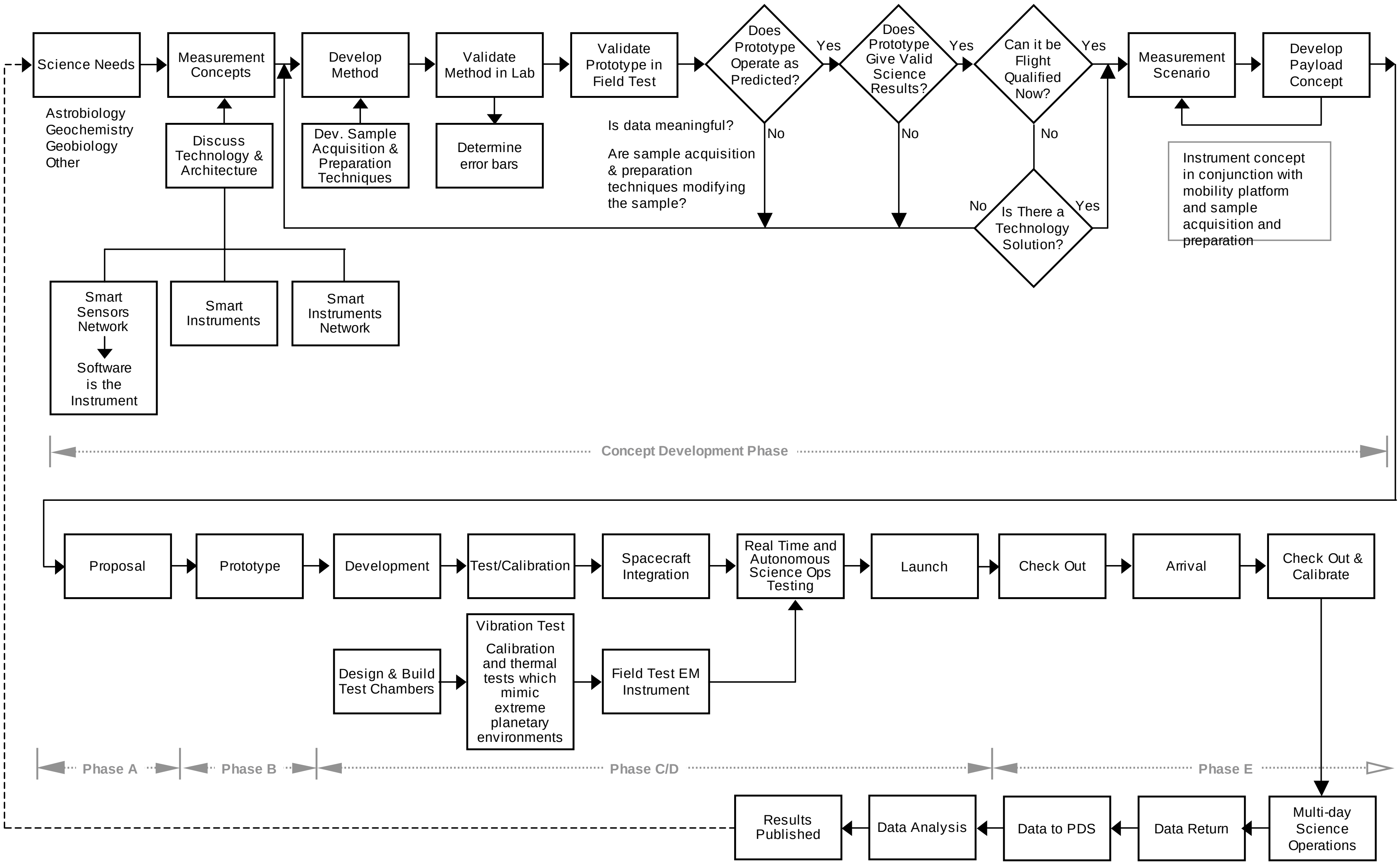
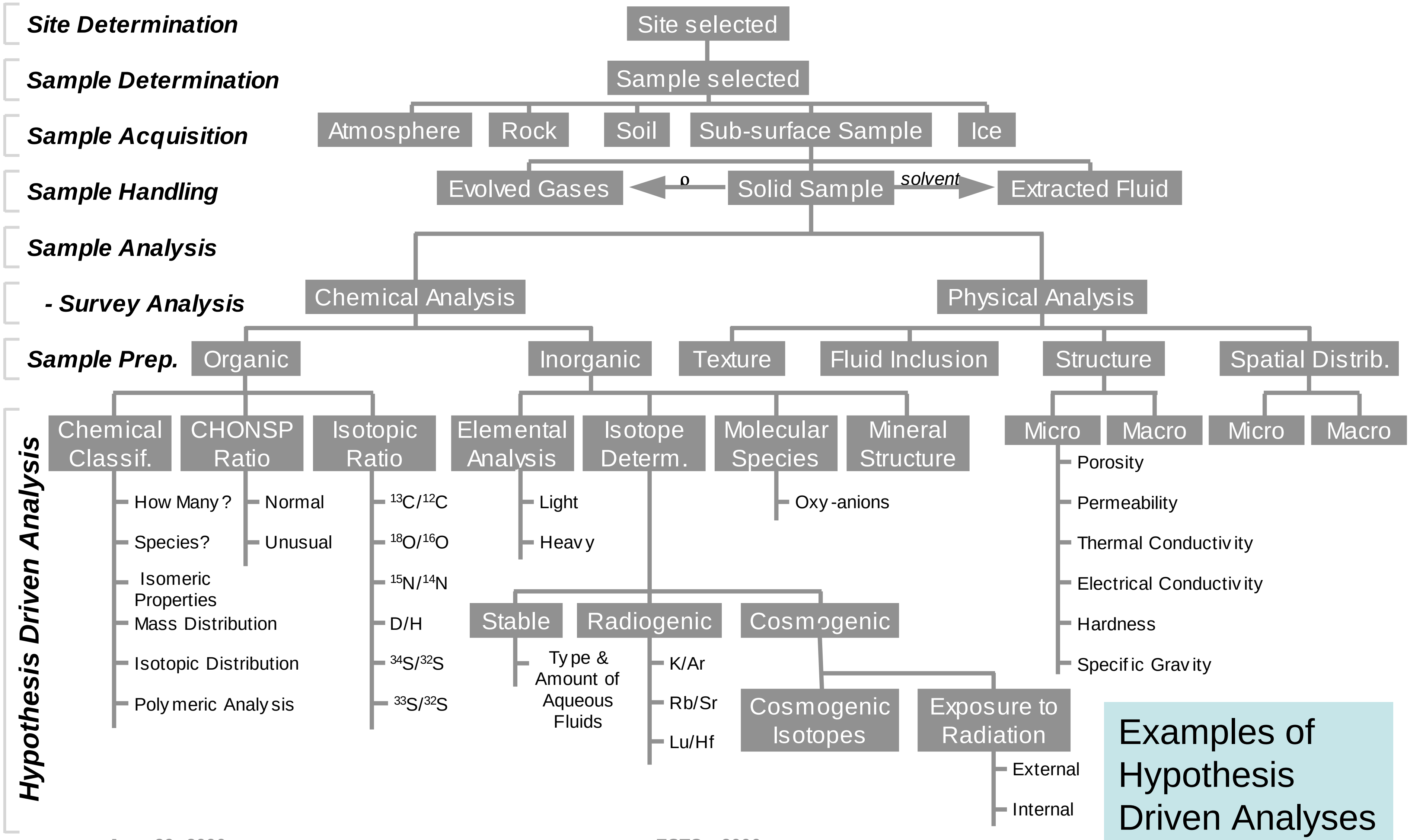
Life Cycles of Remote Sensing compared to In Situ Instrumentation:In Situ



Needed Capabilities For In Situ Science

- Astrobiology science definitions and investigations
- In situ instrument concept, research, and development
- Access methods and sample collection / handling / processing techniques
- Planetary protection methodology

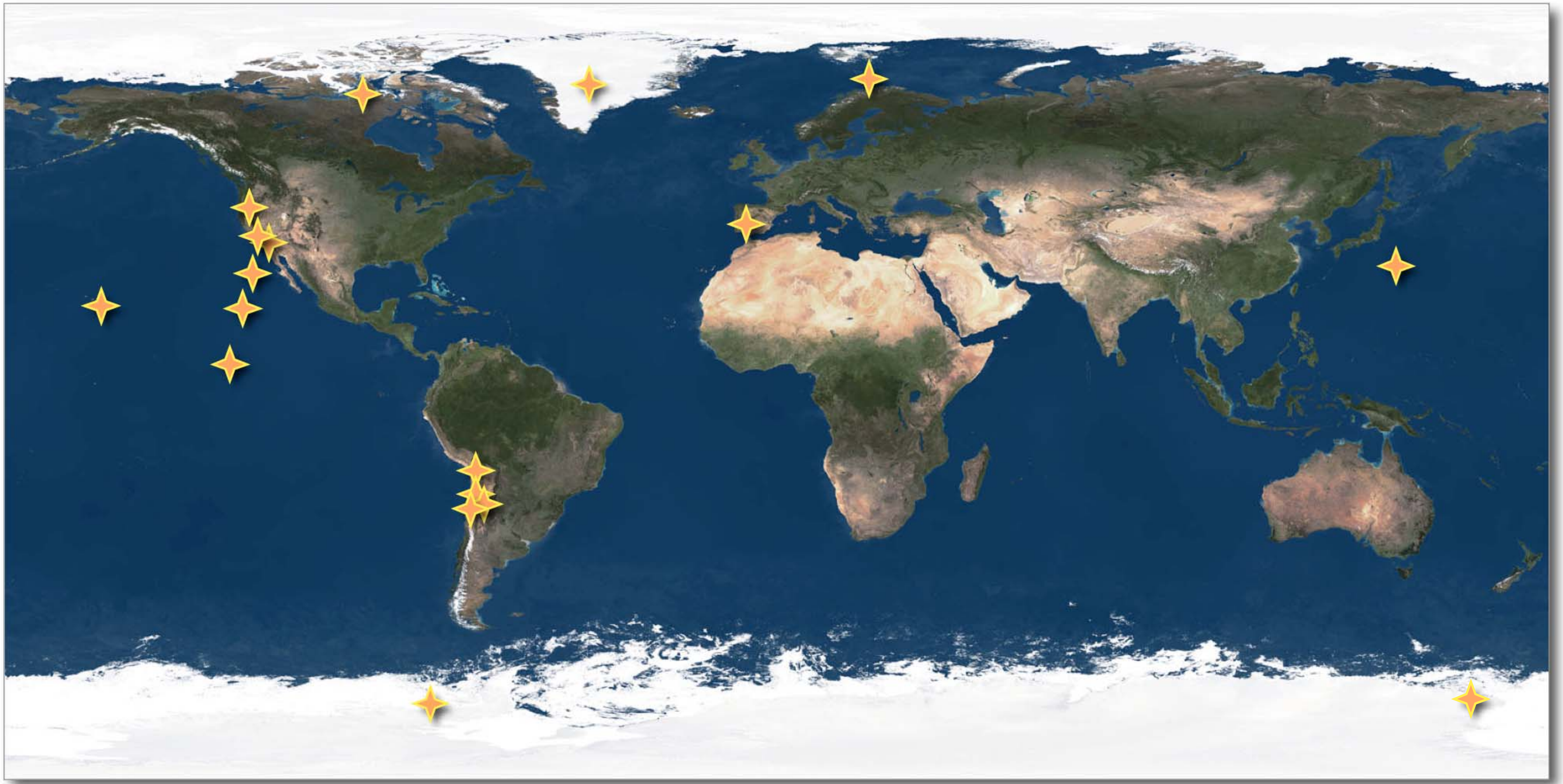
Framework For Putting The Pieces Together



The Wild World of Astrobiology

Astrobiology and In Situ Exploration is a contact sport!

Researchers have been "spanning the globe" in pursuit of answering key scientific and technical questions



Timeline

- **Long timeline for creation of in situ investigations for NASA planetary missions**
  - Establish in situ / astrobiology science community
    - Geology community has come a long way
    - Biology community lagging
  - Creation of accepted definitions and methods of in situ investigations needed
    - Lack of models of performance, calibration, ands system engineering practices

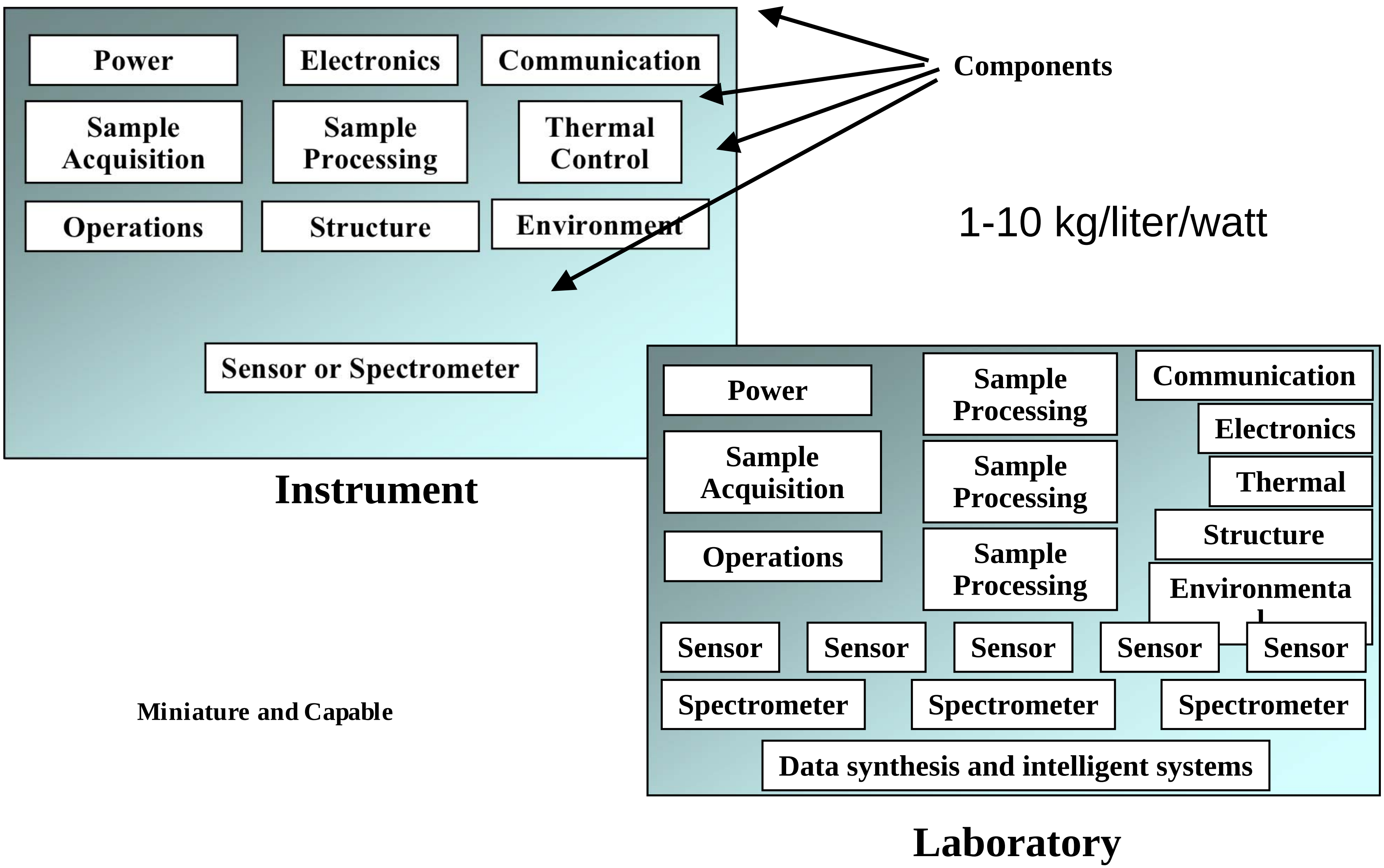
For Flagship Missions in the 2015 – 2020 Time Frame, Science Team and Instrument Development is NOW

Example: MOD

- **Mars Organic Detector (MOD) aka UREY**
  - System to detect and analyze organic compounds in the Martian Environment with high sensitivity and specificity
- **Collaboration with JPL (Frank Grunthaner), UCSD (Jeff Bada), and Richard Mathies (UCB)**
  - Working together over nine years
  - Collaboration has used funding from ASTID, ASTEP (2), PIDDP, MSMT, RTD, AEMC, Grand Challenge
- **All leading to proposal for UREY payload on EXOMARS**
  - Selected by ESA, now looking for selection as a Mission of Opportunity

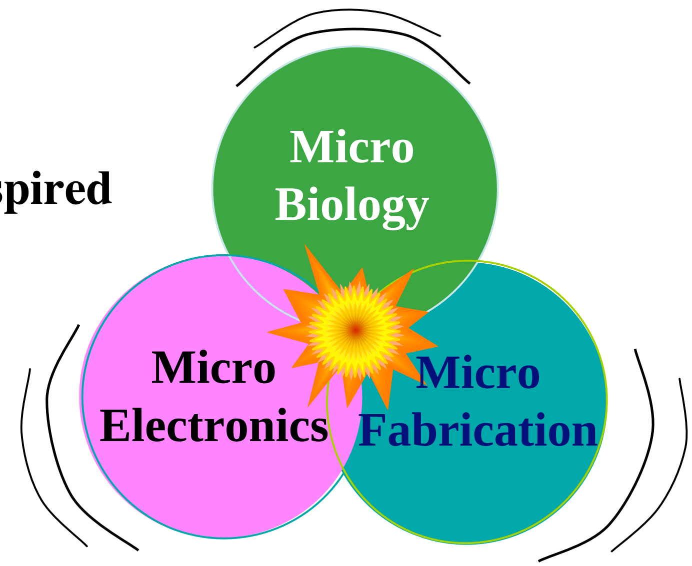
All this for ONE instrument

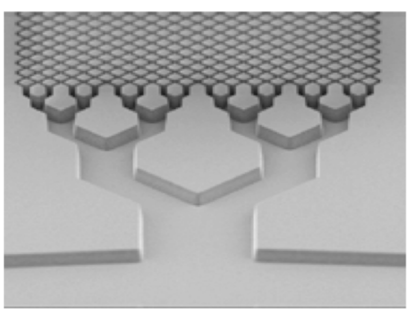
In Situ Sample Analysis Laboratories are more complex



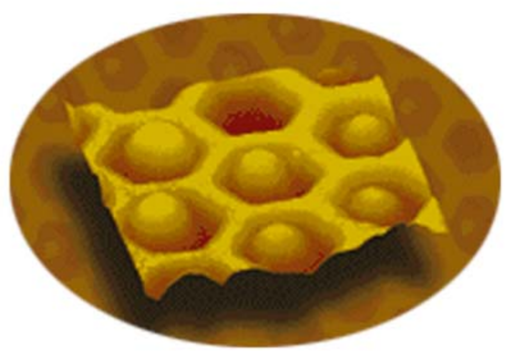
In Situ Sample Analysis Requires Integration of Many Emerging Advanced Concepts

- **Micro fabrication of traditional analytical tools**
- **Advanced sensor concepts, including biologically inspired**
- **Advanced transducer concepts**
- **Advanced micro scale sample handling & preparation technologies**
- **Micro fabrication of supporting technologies such as pumps**
- **Replenish/recycle expendables using in situ resources**
- **Integration**

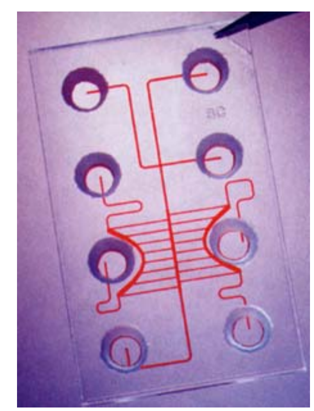




Micro column separator (Purdue)



500-nm micro wells on tip of fiber probe with chemical sensor beads (Tufts)

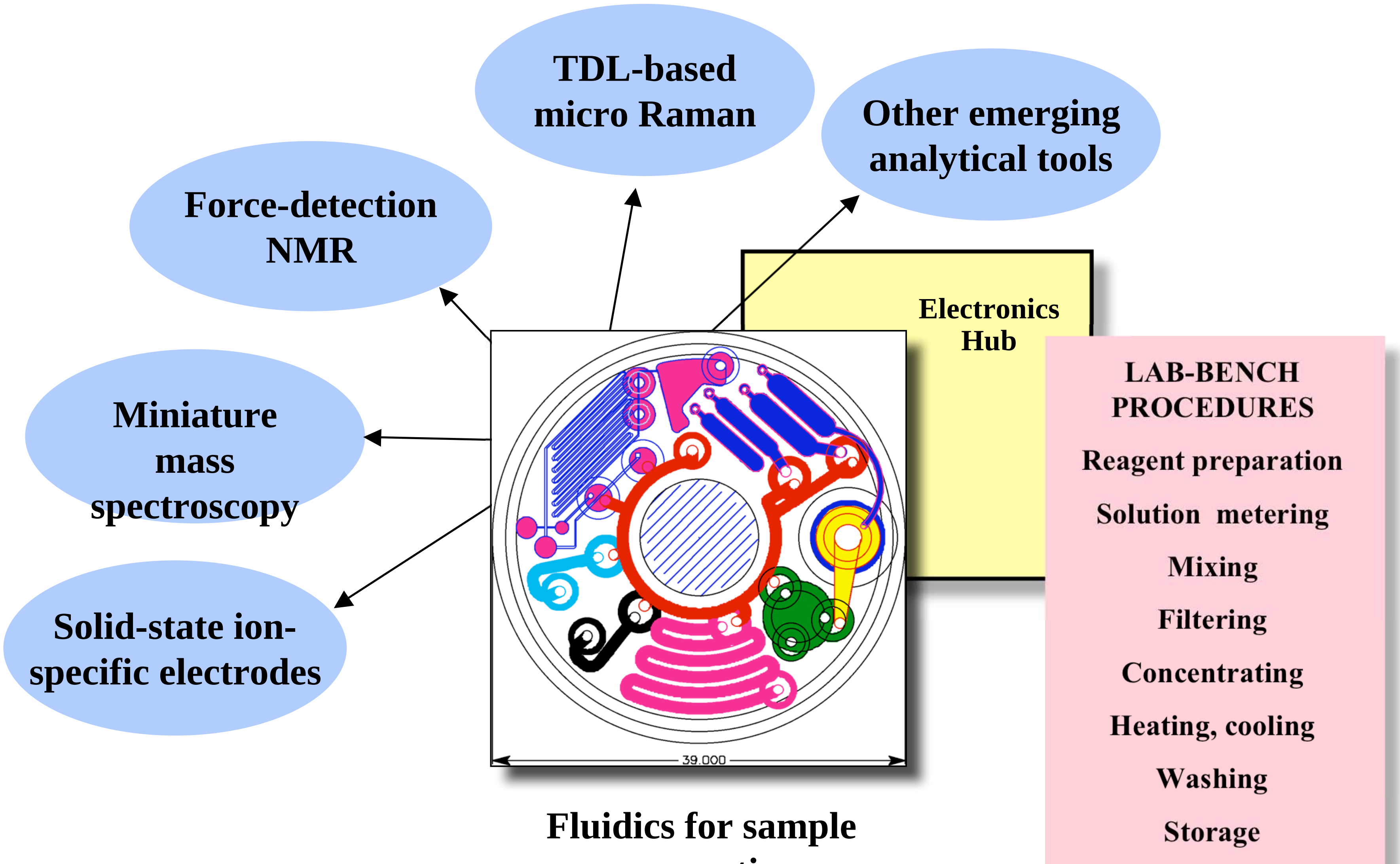


Micro fluidic system (Caliper, Inc.)

Supporting technologies for In Situ Laboratories

- **Microfluidic technologies**
- **Miniature vacuum pumps**
- **Visible, IR and UV Sensors**
- **Advanced miniature fabrication technologies**
  - Micro-machining
- **Advanced Photonics development – lasers**
- **Advanced diffractive optics**
- **Sample acquisition and handling**
  - Acoustic coring
  - Drilling (rock and ice)

Micro-laboratory example



Fluidics for sample preparation

In Situ Instrument Classes

Distance of operation:

- "Local Remote": meters to cm range working range
- "Contact": cm to micron working range
- "Analytical": Sample acquired, processed, and analyzed inside of laboratory

- ⇒ *The first two categories require little to no sample or surface preparation* - a major advantage for rapid assay operations, mass-limited platforms, or for triage in selection of samples for further study or collection

  - Contact Instrument Examples include
    - Microscopy
    - Raman (Visible, UV, IR; wide area or microbeam)
    - Electron Probe, Alpha probe
    - LIBS
    - Reflectance optical spectroscopy (UV, visible, IR, polarization)
    - Magnetic resonance
    - Neutron Spectroscopy

In Situ Instrument Classes

- **Measurement Types**
  - Detection/Classification/Identification of Chemical/Elemental species
    - Mass spectroscopies
    - Chromatography systems
    - X-ray diffraction / Florescence
    - Optical Spectroscopies (Absorption, Raman, Luminescence, etc)
    - Nuclear Magnetic Resonance
    - Almost every other currently available chemical assay is under some stage of development
  - Biological Detection / Identification
    - ATP and QD tagging
    - DPA detection
  - Spatial Detection Methods
    - Optical Microscopy
    - CT X-ray imaging
    - Soft X-ray Photoemissions

Key for Analytical Instrument: Sample Preparation

- **Analytical in situ instruments rely on acquiring and preparing a sample**

- **Necessity to develop sample preparation and extraction techniques that**
  - Offer high efficiency
  - Do NOT bias the measurements to be taken with downstream instruments
  - Offer robust operation - often the limiting factor in lifetime
  - Avoid cross contamination
  - Provide Multiple samples/extracts to instrument suite
  - Operate in reduced gravity conditions

- **Techniques**
  - Pyrolysis
  - Sublimation
  - Polishing
  - Supercritical CO2 extraction
  - Subcritical H20 extraction
  - Microwave extraction

Summary

- In Situ instruments are a unique for NASA missions - lessons from remote sensing often don't apply
- Development of In Situ System Engineering methods is a work in progress
- Defining, integrating and testing of space in situ laboratories is currently more art than engineering
- The power of in situ methods, demonstrated in the lab, is advancing rapidly, offering measurements and science investigations not thought possible